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FOR: VIBRATION LINEAR ACTUATING DEVICE, METHOD OF DRIVING THE SAME DEVICE, AND PORTABLE INFORMATION APPARATUS USING THE SAME DEVICE

VERIFICATION OF A TRANSLATION

Assistant Commissioner for Patents
Washington, D.C. 20231
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I, the below named translator, hereby declare that:

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2. That I am knowledgeable in the English language and in the language of JP2002-102352, and I believe the attached English translation to be a true and complete translation of JP2002-102352.

3. The document for which the attached English translation is being submitted is a patent application on an invention entitled VIBRATION LINEAR ACTUATING DEVICE, METHOD OF DRIVING THE SAME DEVICE, AND PORTABLE INFORMATION APPARATUS USING THE SAME DEVICE.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Date: May 7, 2007

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[Name of the Document] Specification

[Title of the Invention] Linear Vibration Actuating Device, Linear Vibration Actuator Driving Method, and Electronic Apparatus Using the Same

[Claims]

[Claim 1] A linear vibration actuating device comprising:

a linear vibration actuator having a single-phase exciting coil;

a starter for starting the actuator from a state of stop;

a driver having a switching element connected to the coil;

a control output for controlling power to the switching element; and

a zero-cross detector for detecting a zero-cross point of back electromotive force generated in the coil,

wherein a first terminal of the coil is connected to a power supply terminal, and a second terminal of the coil is connected to the switching element, and the zero-cross point is detected by the zero-cross detector from the second terminal, and the detected signal is returned to the control output.

[Claim 2] A linear vibration actuating device comprising:

a linear vibration actuator;

a starter for starting the actuator from a state of stop;

a driver of the actuator;

a control output for controlling power to the actuator;

a zero-cross detector for detecting a zero-cross point of back electromotive force generated in the actuator; and

a zero-cross monitor having a function of checking that signals are repeatedly inputted from the zero-cross detector and generating a single

signal for re-starting when emission of signals from the zero-cross detector is discontinued.

[Claim 3] A linear vibration actuating device comprising:

a linear vibration actuator;

a starter for starting the actuator from a state of stop;

a driver of the actuator;

a control output for controlling power to the actuator;

a zero-cross detector for detecting a zero-cross point of back electromotive force generated in the actuator, and further,

a function of stopping the operation of the zero-cross detector for a specific length of time after the end of output from the driver.

[Claim 4] The linear vibration actuating device of claim 1, wherein the zero-cross point is detected by the zero-cross detector via a level shift section from the second terminal, and the detected signal is returned to the control output.

[Claim 5] The linear vibration actuating device of claim 1, further comprising a timing adjuster for generating a signal for driving the switching element in a delayed fashion after the zero-cross point is detected by the zero-cross detector from the second terminal.

[Claim 6] The linear vibration actuating device of claim 5, wherein the timing adjuster includes a phase locked loop group.

[Claim 7] The linear vibration actuating device of any one of claims 1 to 6, wherein a pulse width modulator is added to the control output.

[Claim 8] A linear vibration actuator driving method including:

a step of detecting a zero-cross point of back electromotive force from

a coil of the linear vibration actuator to generate a zero-cross detecting signal, and

a step of inputting the zero-cross detecting signal obtained in the step to a control signal forming section to form a signal for driving a switching element connected to the coil in accordance with the zero-cross detecting signal.

[Claim 9] A linear vibration actuator driving method comprising:

a step of executing analog-digital conversion of back electromotive force form a coil of a linear vibration actuator, and

a step of inputting analog-digital conversion signal obtained in the above step to a control signal forming section to form a signal so as to drive a switching element connected to the coil in accordance with the analog-digital conversion signal.

[Claim 10] The linear vibration actuator driving method of claim 9, further comprising a step of signal forming so as to drive the switching element connected to the coil when the back electromotive force obtained from the analog-digital conversion signal is maximized in amplitude.

[Claim 11] An electronic apparatus comprising a linear vibration actuator of any one of claims 1 to 7.

[Claim 12] A portable telephone comprising a linear vibration actuator of any one of claims 1 to 7.

[Claim 13] An electronic apparatus including:

an apparatus substrate;

a linear vibration actuator which has a single-phase coil and is mounted on the substrate;

a starter for starting the actuator from a state of stop;

a driver having a switching element connected to the coil;

a control output for controlling power supply to the switching element;

a zero-cross detector for detecting a zero-cross point of back electromotive force generated in the coil, and

a driving unit configured in that a first terminal of the coil is connected to a power supply terminal, a second terminal of the coil is connected to the switching element, the zero-cross point obtained at the second terminal is detected by the zero-cross detector, and the detected signal is returned to the control output.

[Claim 14] A portable telephone including:

an apparatus substrate;

a linear vibration actuator which has a single-phase exciting coil and is mounted on the substrate;

a starter for starting the actuator from a state of stop;

a driver having a switching element connected to the coil;

a control output for controlling power supply to the switching element;

a zero-cross detector for detecting a zero-cross point of back electromotive force generated in the coil, and

a driving unit configured in that a first terminal of the coil is connected to a power supply terminal, a second terminal of the coil is connected to the switching element, the zero-cross point from the second terminal is detected by the zero-cross detector, and the detected signal is

returned to the control output.

[Claim 15] An electronic apparatus comprising a linear vibration actuating device which is operated by the driving method of any one of claims 8 to 10.

[Claim 16] A portable telephone comprising a linear vibration actuator which is operated by the driving method of any one of claims 8 to 10.

[Claim 17] An electronic apparatus comprising:

an apparatus substrate, and

a linear vibration actuator,

wherein the actuator includes a fixed inner yoke having a single-phase exciting coil and a movable yoke having a magnet, and an outer yoke vibrates in maximum amplitude in a main shaft direction of the inner yoke outside a periphery of the inner yoke, and the actuator is mounted in such manner that the main shaft direction is vertical to the substrate.

[Claim 18] An electronic apparatus including:

a support substrate;

a linear vibration actuator retained by the support substrate in such manner that vibrating direction is perpendicular to the support substrate; and

a driving unit for driving the actuator.

[Detailed Description of the Invention]

[0001]

[Field of the Invention]

The present invention relates to a so-called linear vibration actuating device that is an electromagnetic actuator, a linear vibration

actuator driving method, and an electronic apparatus using the same, and more particularly, it relates to assurance of reliable and stable driving of the electromagnetic actuator.

[0002]

[Background Art]

For driving a conventional vibration actuator (hereinafter called actuator), a push-pull driving circuit formed of four switching elements is used (Japanese Laid-open Patent 2001-25706).

[0003]

Fig. 18 is a circuit diagram of the example in which vibration actuator 5 connected in the middle of the bridge structure is operated by driving unit 4 with starter 1, control output 2, driving pulse setter 3, and four switching elements Q1 to Q4 connected in a bridge structure fashion.

[0004]

Actuator 5 is, as shown in the structural diagram of Fig. 19, configured in that mover 7 including magnet 6 is suspended by a pair of elastic members, for example, plate springs 8, 9, and attracted and repulsed by electromagnets 10, 11 to be vibrated.

[0005]

The operation of driver 4 is such that power polarity to electromagnets 10, 11 is controlled so that mover 7 moves in positive direction when switching elements Q1, Q4 are ON and switching elements Q3, Q2 are OFF with respect to four switching elements Q1 to Q4 shown in Fig. 18, and contrarily, mover 7 moves in negative direction when switching elements Q1, Q4 are OFF and switching elements Q2, Q3 are ON.

[0006]

[Problems to be Solved by the Invention]

In the background art, as shown by the circuit diagram in Fig. 18, since a push-pull driving circuit formed of four switching elements is employed, the elements of the driving circuit are many, and in addition, they are supplied with power when mover 7 is moved in both of the positive and negative directions, causing the control operation to become complicated and the cost to be increased.

[0007]

[Means to Solve the Problem]

The linear vibration actuating device of the present invention comprises a linear vibration actuator (hereinafter called actuator) having a single-phase exciting coil (hereinafter called coil), a starter for starting it from a state of stop, driver having an element connected to the coil, a control output for controlling the power to the switching element, and a zero-cross detector for detecting a zero-cross point of back electromotive force generated in the coil, wherein a first terminal of the coil is connected to a power terminal, and a second terminal thereof is connected to the switching element, and the zero-cross point of back electromotive force from the second terminal is detected by the zero-cross detector, and the detected signal is returned to the control output, thereby controlling the power to the switching element. Accordingly, it is possible to make the operation of the driver reliable and stable.

[0008]

Further, in the linear vibration actuating device, after the zero-cross

point from the second terminal is detected by the zero-cross detector, the generation of a driving signal of the switching element is delayed by a desired period by means of a timing adjuster, and thereby, it is possible to output the driving pulse of the actuator in proper timing.

[0009]

Also, the linear vibration actuating device of the present invention comprises an actuator, a starter for starting the actuator from a state of stop, driver of the actuator, a control output for controlling the power to the actuator, a zero-cross detector for detecting a zero-cross point of back electromotive force generated by the actuator, and a zero-cross monitor having a function of generating a single signal to re-start when the signal from the zero-cross detector is discontinued. Accordingly, even in case the zero-cross of back electromotive force generated in the coil is not detected for some reason, it is possible to re-start the actuator and to continue the linear vibration.

[0010]

Furthermore, the linear vibration actuating device of the present invention comprises an actuator, a starter for starting the actuator from a state of stop, a driver, a control output for controlling the power to the actuator, and a zero-cross detector for detecting a zero-cross point of back electromotive force generated by the actuator, and also, a function of stopping the detecting operation of the zero-cross detector for a specific length of time when the output from the driver is ended. Accordingly, it is possible to reliably detect the zero-cross point of back electromotive force generated in a predetermined timing.

[0011]

Also, the linear vibration actuator driving method of the present invention includes a step of executing analog-digital conversion of back electromotive force from a single-phase exciting coil of the actuator, and a step of inputting the analog-digital conversion signal obtained in the step to a control signal forming section to form the signal so as to drive the switching element connected to the coil in accordance with the analog-digital conversion signal. Accordingly, it is easy to realize the main system of the driving control unit of the actuator by using microcomputer (hereinafter called micom) control. And, the switching element is driven in timing including a point delayed by 1/4 period from the zero-cross point of back electromotive force, and thereby, it is possible to efficiently operate the actuator and to reduce the load to the power source.

[0012]

Further, the electronic apparatus of the present invention comprises an actuator retained on a support substrate in such manner that the main vibration direction is perpendicular to the support substrate, and a driving device for driving the actuator. Accordingly, the user may sense the operation of the actuator mounted in the electronic apparatus in maximum amplitude of detection.

[0013]

[Description of the Preferred Embodiments]

The preferred embodiments of the present invention will be described in the following with reference to the drawings.

[0014]

Fig. 1 is a structural block diagram of an actuator driving device in the first preferred embodiment of the present invention. This device comprises starter 1, control output 2, driving pulse setter 3, actuator 5, actuator driver (hereinafter called driver) 12, and zero-cross detector 13.

[0015]

Here, actuator 5 includes an inner yoke having a single-phase exciting coil as a stator, and an outer yoke as a vibrator, wherein the vibrator linearly vibrates. In driver 12, to the other end of coil of actuator 5 with one end connected to the positive electrode of circuit power source Vcc is connected the collector terminal of switching element Q5 formed of NPN transistor for driving it, and the emitter terminal is connected to the negative electrode (ground potential) of the circuit power source Vcc. And, in zero-cross detector 13, the zero-cross point of back electromotive force of coil is detected from the other end of coil of actuator 5. That is, the zero-cross point of back electromotive force is detected at a point where the vibration of actuator 5 is maximized in amplitude, and after detecting the point, the signal is returned to control output 2. In this way, the operation of driver 12 becomes reliable and stabilized.

[0016]

In driver 12, NPN transistor is used for output switching element Q5 as described above, but it is of course possible to use PNP transistor. In that case, the emitter of PNP transistor is connected to the positive electrode of circuit power Vcc, and the collector thereof is connected to one end of the coil, and the other end of the coil is connected to the negative electrode (ground potential) of circuit power Vcc, and thereby, it is possible

to detect the zero-cross point of back electromotive force from one end of the coil.

[0017]

Also, in this device, there is provided a function of detecting the zero-cross point of back electromotive force of the actuator, and it is possible to excite the vibrator with poser supplied to the coil in only one direction. That is, the vibrator is moved in positive direction with an electromagnetic force obtained by power applied to the coil, and on the other hand, it is moved in negative direction with only repulsion and attraction of an elastic member, and thereby, it is possible to achieve the power saving purpose.

[0018]

Further, for detecting the zero-cross point of back electromotive force, the back electromotive force generated from one end of the coil is used, thereby making it unnecessary to install surplus elements such as a coil for detection.

[0019]

Fig. 2 (A) is a structural block diagram of an actuator driving device in the second preferred embodiment of the present invention. This device comprises starter 1, control output 2, driving pulse setter 3, driver 12, and zero-cross detector 13, and also, zero-cross monitor 14. This is intended to provide the device with a function of checking whether or not the zero-cross detection is continuously performed so that the device can be re-started even in case the zero-cross detection cannot be performed or the vibrator stops vibrating due to some trouble.

[0020]

Fig. 2 (B) is a circuit diagram of zero-cross monitor 14 and its periphery. It has a function of generating a single signal for re-start even in case no signal is generated in zero-cross detector 13.

[0021]

Fig. 2 (C) is a timing diagram for the comparison of output signal a - 2 of zero-cross detector 13 in zero-cross detection of normal signal a - 1 and output signal b - 2 of zero-cross detector 13 in zero-cross detection of abnormal signal b - 1. Due to a re-triggering function after a specific hold period in zero-cross detector 13, when a stop signal output from zero-cross detector 13 in zero-cross detection of abnormal signal b - 1 is received, then a single signal is generated by one-shot multi-vibrator 15, 16. In this way, it is possible to re-start the driver 12. Here, another one-shot multi-vibrator 17 serves to produce a driving pulse from the signal of zero-cross detector 13, while OR-gate circuit 18 serves to allow passage of the signal from one of the two one-shot multi-vibrators 16, 17. The circuit for re-start can be realized by using a circuit that has a re-triggering function and makes a single stable operation.

[0022]

Fig. 3 shows a circuit structure of back electromotive force amplifier 19 disposed in the front stage of zero-cross detector 13 when the operation of zero-cross detector 13 is not stabilized due to insufficient back electromotive force to be detected. It stabilizes the operation of zero-cross detector 13 and assures reliable driving of output switching element Q5.

[0023]

Fig. 4 is a diagram showing the installation of level shift 20 between

zero-cross detector 13 for back electromotive force and detection end for back electromotive force of actuator 5. Level shift 20 is useful for unification of circuit power source Vcc, and it is possible to freely set the reference voltage of back electromotive force amplifier 19 to Vcc/2 for example in accordance with circuit power source Vcc.

[0024]

Fig. 5 shows an example of configuration provided with a measure for preventing output switching element Q5 from being damaged when the back electromotive force generated in the coil of actuator 5 becomes abnormally high. In this example, protective diode 21 is connected to actuator 5, and thereby, it is possible to make the driving circuit appropriate and stable. Further, in order to shorten the time of back electromotive force generated in the coil of actuator 5 after output switching element Q5 is turned OFF, it is preferable to insert a Zener diode being conductive at a specific voltage in series and in a direction opposite to protective diode 21.

[0025]

Fig. 6 is a circuit for preventing faulty detection of zero-cross signal due to the influence of back electromotive force caused by coil inductance of the actuator generated when output switching element Q5 is OFF in such a case that the driving pulse of the actuator is outputted for relatively short time. That is, in the circuit of Fig. 6 (A), when the zero-cross detection signal is not normal (hereinafter called mis-operation signal), as shown in Fig. 6 (B), due to back electromotive force with switching element Q5 turned OFF, AND-gate circuit 22 and one-shot multi-vibrator 23, 24 are disposed therebetween to form a mask signal for deleting the mis-operation signal,

thereby stabilizing the ON signal of switching element Q5.

[0026]

Also, after zero-cross detection, the power consumed by the actuator can be reduced by slightly delaying the driving timing of the switching element. That is, the generation of switching element driving signal is delayed by a timing adjusting circuit after zero-cross detection, and thereby, it is possible to drive the actuator at a point close to zero-cross with an amplitude that is said from experience to be excellent in efficiency.

[0027]

Fig. 7 is a timing chart provided with delay time t between zero-cross detection of back electromotive force and generation of switching element driving signal.

[0028]

In this case, the timing adjusting circuit can be realized by a time constant delay circuit as well, but by using phase locked loop (PLL) 25 shown by the circuit of Fig. 8, it is possible to reliably follow the change of resonance point of the actuator. In the circuit of Fig. 8, a specific delay time is set via PLL 25 after zero-cross detection, thereby enabling the generation of switching element driving signal in optional timing with respect to vibration of the actuator.

[0029]

Fig. 9 shows a driving signal waveform with pulse width modulator (PWM) added to the control output as an output signal of the switching element with regard to a switching element driving signal. This is useful when the coil resistance of the actuator is less, causing excessive current to

flow with switching element turned OFF. In this way, it is possible to reduce the power consumed for driving the actuator.

[0030]

Fig. 10 (A) is a block diagram of a circuit for realizing the main system of a drive controller of the actuator by means of micom control in the second preferred embodiment. In this case, for detecting the zero-cross of back electromotive force from the coil of actuator 5, zero-cross detection is performed by inputting the back electromotive force to micom controller 27 via analog-digital (AD) converter 26, and at the same time, the switching element is driven in the timing.

[0031]

Fig. 10 (B) is a timing chart showing the relationship between the back electromotive force then subjected to AD conversion and the vibration waveform of actuator. As is obvious in the figure, the zero-cross of converted back electromotive force stands for the peak of vibration waveform of the actuator. Also, the zero-cross point of vibration waveform appears at a point delayed by phase of 1/4 cycle from the zero-cross point of vibration waveform. In any of the timing, the switching element can be driven, but it can be more efficiently driven if switching element Q5 is turned ON within a period including the zero-cross point of vibration waveform, thereby giving kinetic energy to the movable member of actuator at its maximum speed.

[0032]

Also, in the configuration shown in Fig. 10 (A), it is preferable to dispose level shift 20 configured as shown in Fig. 4 between the back

electromotive force detecting end of actuator 5 and AD converter 26, and further, it is preferable to additionally dispose back electromotive force amplifier 19. Level shift 20 is useful for unification of circuit power source Vcc, and the reference voltage of back electromotive force amplifier 19 can be optionally set in accordance with circuit power source Vcc.

[0033]

(First Exemplary Embodiment)

Fig. 11 is a circuit diagram of the device in the first exemplary embodiment of the present invention. An example of structure of the actuator used in this device will be described with reference to the sectional view of Fig. 12.

[0034]

In Fig. 12, actuator 30 comprises outer yoke 31 which is polygonal or preferably cylindrical, inner yoke 32 which is cylindrical and internally disposed at a predetermined interval, coil 33 wound on inner yoke 32, and magnet 34 which is disposed inside the outer yoke 31 and next to and opposite to inner yoke 32. Magnetic material is used for inner yoke 32 and outer yoke 31. Also, it is preferable to configure these with radial laminate of thin steel sheets molded, that is, laminating them on shaft 35 at the center or to use sintered magnetic material instead.

[0035]

Inner yoke 32 is fixed in substrate 36 by using shaft 35 secured on substrate 36 and, as needed, a depression (not shown) formed in the inner surface of substrate 36. Substrate 36 is formed, for example, by heat-resisting resin whose glass transition temperature is higher than

90degC.

[0036]

Also, the top and bottom surfaces of inner yoke 32 are respectively provided with ring-like plate springs 37, 38 which are fixed on the inner ends thereof. And, on the outer end of ring-like plate spring 37, 38 is fixed outer yoke 31 which is held therebetween, and thereby, it is possible to realize up and down vibrations vertical to the surface of plat spring 37, 38 such that the outer yoke vibrates in maximum amplitude in a direction parallel to shaft 35 at the peripheral surface of inner yoke.

[0037]

Both ends of coil 33 are connected to conductive lands 39, 40 disposed on the bottom of substrate 36, and power is supplied via lands 39, 40. With power supplied to the coil, magnetic flux is generated in the inner yoke, and due to the magnetic flux, the outer yoke moves in one direction upward or downward, and when power supply to coil 33 is discontinued, it moves in the restoring direction due to the resilient action of plate spring 37, 38. Accordingly, up and down vibrations vertical to the surface of plate spring 37, 38 are produced such that outer yoke 31 vibrates in maximum amplitude in a direction parallel to shaft 35 as power supply to coil 33 is turned ON/OFF.

[0038]

In the device of Fig. 11, when switch 41 of starter 1 is turned ON with an external signal, the signal is inputted to the driving pulse setter and control output 2 via NAND gate circuit and AND gate circuit 22, and the output of control output 2 is inputted to the control terminal of

switching element Q5 through the OR gate, and thereby, switching element Q5 of the driver of actuator 5 is turned ON/OFF in accordance with the output cycle of control output 2 to drive actuator 5. The back electromotive force is led into zero-cross detector 13 from actuator 5 via level shift 20 and back electromotive force amplifier 19, and the output is led into the NAND gate circuit and also to two flip-flop circuits (one-shot multi-vibrator) 43, 45, realizing stable operation of switching element Q5 with the re-starting signal in stop mode and the signal of starter 1. In this exemplary embodiment device, flip-flop circuit (one-shot multi-vibrator) 24 serves to form a mask signal as a measure for zero-cross misoperation, and two flip-flop circuits (one-shot multi-vibrator) 43, 45 are signal generator (timing setter) provided for re-starting.

[0039]

From the experience, the actuator shown in Fig. 12 can be operated with the vibration cycle set at 100 to 200Hz in case the cylinder of outer yoke 31 is about 10 mm in diameter and about 3 mm in length, and the vibration is about 1N. Particularly, when the vibration cycle matches the inherent vibration or resonance vibration by outer yoke 31 and plate spring 37, 38, it is possible to realize effective and efficient driving with stable vibrations.

[0040]

Fig. 13 is a signal processing flow chart of the first exemplary embodiment device shown in Fig. 11. The timing setters, timers I, II, III, IV, respectively correspond to flip-flop circuits (one-shot multi-vibrators) 23, 43, 24, 45 of Fig. 11, and the flow of Fig. 13 shows the correspondence with

respect to the software of the exemplary embodiment device.

[0041]

Looking at the flow chart of signal processing in Fig. 13 in correspondence to the circuit operation of the device shown in Fig. 11, first with switch 41 of the starter turned ON, timer II for actuator start pulse output operates when the actuator driving command decision and starting decision are Yes. Then start pulses for a span of time of timer II are outputted. When the decision of timer II becomes 0, the actuator start pulse output turns OFF and timer II stops, then vibration is started. In this case, when the back electromotive force zero-cross decision is Yes, timer I and timer IV operate according to the decision so that actuator driving pulse output is generated at the back electromotive force zero-cross point, and it flows until stop of timer I with actuator driving pulse output turned OFF through the decision of timer I. And, stop of timer I is followed by the operation of timer III, and subsequently, when timer III stops operating, the loop goes back to start signal. Also, the back electromotive force zero-cross decision is the decision of timer IV as well, and the loop is returned to the start decision to turn into driving pulse output for re-start in stop mode of the actuator. In case of no start signal, the control output is OFF, and all timers I to IV are in stop mode.

[0042]

The above-mentioned process can be easily configured with software of a microcomputer by using the flow chart of Fig. 13. An example of hardware in that case is as shown in Fig. 10 (A). Taking AD-converted back electromotive force into a microcomputer or the like, it is possible to

detect proper timing other than the zero-cross of back electromotive force and to control the timing of driving pulse at a proper position of vibration of the actuator. For example, the maximum value (maximum positive or negative value) of amplitude of the back electromotive force is detected and the driving pulse of the actuator is outputted. From the experience, the output of driving pulse in this timing is highest in efficiency.

[0043]

(Second Exemplary Embodiment)

Fig. 14 is a circuit diagram of the second exemplary embodiment device of the present invention. It is effective to use when the coil of actuator 5 is less in resistance and excessive current flows with switching element Q5 turned ON. This device has a circuit configuration shown in Fig. 11, which is additionally provided with pulse width modulator 46. In pulse width modulator 46, the pulse width of the signal from the control output as the input signal of the switching element is modulated, and thereby, it is possible to stabilize driving operation of the actuator and to reduce the power consumption.

[0044]

(Third Exemplary Embodiment)

Fig. 15 is a circuit diagram of the third exemplary embodiment device of the present invention. This device has a circuit configuration shown in Fig. 11, which is additionally provided with two-stage flip-flop circuit 47 as a zero-cross controller. Accordingly, actuator driving pulse can be outputted in timing delayed from the back electromotive force zero-cross point, and it is possible to drive the driver 12 at a point close to

the zero-cross of amplitude that is said to be excellent in efficiency from the experience.

[0045]

(Fourth Exemplary Embodiment)

Fig. 16 is a circuit diagram of the fourth exemplary embodiment device of the present invention. This device has a circuit configuration shown in Fig. 11, which is additionally provided with PLL 25 as a zero-cross controller. Accordingly, even in case the resonance point of actuator 5 changes as against the zero-cross detecting signal as a reference, the driving signal of switching element Q5 can be reliably generated in proper timing with respect to the vibration of actuator 5.

[0046]

(Fifth Exemplary Embodiment)

Next, as another exemplary embodiment device of the present invention, a portable telephone mounted with the actuator of the present invention will be described as an example. Fig. 17 is a structural sectional view thereof. Actuator 30 in Fig. 17 has, for example, a structure described in the first exemplary embodiment, and actuator 30 is directly mounted on machine substrate 51 with its main shaft (corresponding to shaft 35 in Fig. 12) vertically positioned.

[0047]

Actuator 30 has a terminal land disposed on the bottom surface thereof which is directly brazed on a land disposed on the top surface of machine substrate 51. Substrate 51 includes driving circuit component 52 of actuator 30 together with the circuit components of the machine.

Battery 54 is housed in casing 53 of machine 50, and power is supplied from battery 54 to the circuit of machine main body and each part of the driving circuit of actuator 30. And, in the actuator with the coil of inner yoke supplied with power, outer yoke is attracted or repulsed by the action of its magnetic field, and with power to the coil discontinued, it reacts to the action of the resilient plate spring, and thereby, the vibration is maximized in amplitude in a direction vertical to the surface of machine substrate 51. In a portable telephone, as the start signal of actuator 30, a received signal is used to operate the actuator, and the vibration can be detected as a received signal of maximum amplitude vibration at the detection surface.

[0048]

(Advantages of the Invention)

According to the device of the present invention, power supplied from the circuit power source to the coil of actuator is controlled by ON/OFF operation of a single switching element, and further, the back electromotive force zero-cross of the coil is detected from the other end of the coil of actuator, and the signal is returned to the control output, thereby simplifying the circuit configuration of the driver of the actuator and making the operation reliable and stable, and it is possible to reduce the power consumed for realizing the driving operation.

[0049]

Also, according to the present invention, the main system of the drive controller of the actuator can be easily realized by means of microcomputer control, and it is possible to further reduce the size of the device.

[0050]

Further, according to the apparatus of the present invention, the operation of electronic apparatus can be reliably and stably detected by detecting maximum amplitude vibration on a detection surface. Accordingly, it is very useful for small-sized portable telephones because of being able to detect the operation by vibrations at high amplitudes instead of voice.

[Brief Description of the Drawings]

Fig. 1 is a structural block diagram of the device in one preferred embodiment of the present invention.

Fig. 2 (A) is a structural block diagram of the device in the preferred embodiment of the present invention.

Fig. 2 (B) is a circuit diagram of an essential portion of the device.

Fig. 2 (C) is an operation timing chart of the device.

Fig. 3 is a circuit diagram of an essential portion of the device in the preferred embodiment of the present invention.

Fig. 4 is a circuit diagram of an essential portion of the device in the preferred embodiment of the present invention.

Fig. 5 is a circuit diagram of an essential portion of the device in the preferred embodiment of the present invention.

Fig. 6 (A) is a circuit diagram of an essential portion of the device in the preferred embodiment of the present invention.

Fig. 6 (B) is a timing chart of the operation of the device.

Fig. 7 is a timing chart of the device in the preferred embodiment of the present invention.

Fig. 8 is a block diagram of an essential portion of the device in the preferred embodiment of the present invention.

Fig. 9 is a signal waveform chart of an essential portion in the preferred embodiment of the present invention.

Fig. 10 (A) is a block diagram of an essential portion in the second preferred embodiment of the present invention.

Fig. 10 (B) is a waveform chart of the operation of the device.

Fig. 11 is a circuit diagram of the device in the exemplary embodiment of the present invention.

Fig. 12 is a sectional view of a linear vibration actuator used in the exemplary embodiment of the present invention.

Fig. 13 is a signal processing flow chart of the device in the exemplary embodiment of the present invention.

Fig. 14 is a circuit diagram of the device in the second exemplary embodiment of the present invention.

Fig. 15 is a circuit diagram of the device in the third exemplary embodiment of the present invention.

Fig. 16 is a circuit diagram of the device in the fourth exemplary embodiment of the present invention.

Fig. 17 is a structural sectional view of an electronic apparatus of the present invention.

Fig. 18 is a driving circuit diagram of a vibration actuator in a conventional example.

Fig. 19 is a structural diagram in principle of a linear vibration actuator.

[Description of the Reference Numerals and Signs]

1	Starter
2	Control output
3	Driving pulse setter
5	Linear vibration actuator
12	Actuator driver
13	Zero-cross detector
14	Zero-cross monitor
19	Back electromotive force amplifier
20	Level shift

[Name of the Document] Abstract

[Abstract]

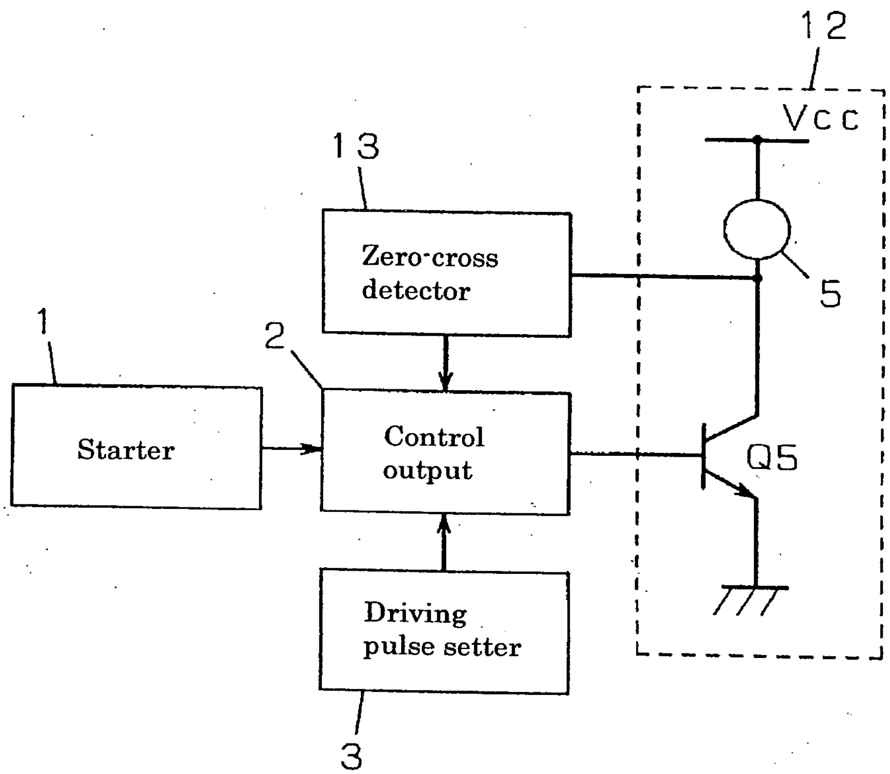
[Object] The object of the invention is to realize a linear vibration actuator of which the driving circuit is structurally simple and less in power consumption for power control operation.

[Means to Solve the Problem] Power supply from the circuit power source to the single-phase exciting coil of linear vibration actuator 5 is controlled by ON/OFF operation of a single switching element, and further, zero-cross point of back electromotive force of the single-phase exciting coil is detected from the other end of single-phase exciting coil of actuator 5, and the signal is returned to control output 2, and thereby, it is possible to simplify the circuit configuration of the actuator driver, to make the operation reliable and stable, and also, to realize the reduction of power consumed for the driving operation. And, when this device is mounted in an electronic apparatus such as a portable telephone with the actuator held on a support substrate in such manner that the direction of its main vibration is perpendicular thereto, it is possible to inform the user of the actuator operation at maximum amplitude on the detection surface.

[Selected Drawing] Fig. 1

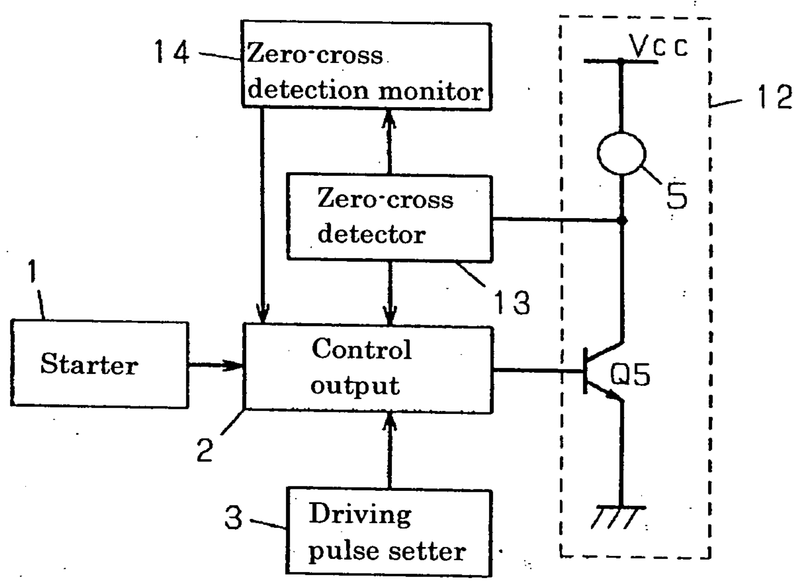
[Name of the Document] Drawing

[Fig. 1]



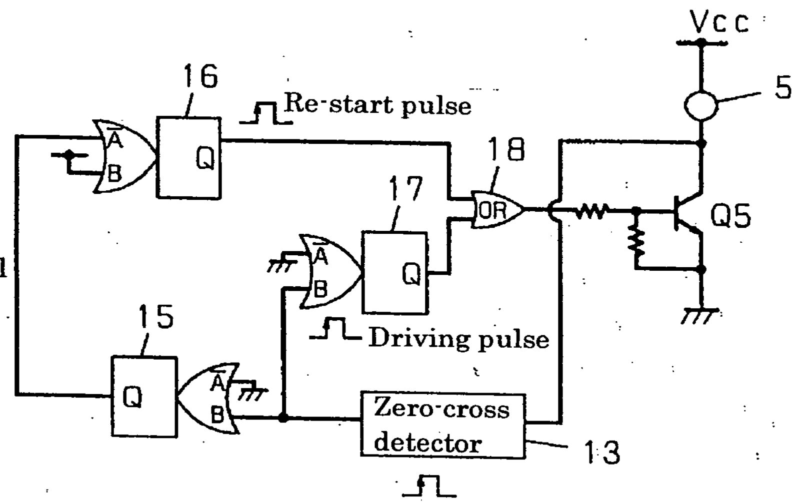
[Fig. 2]

(A)



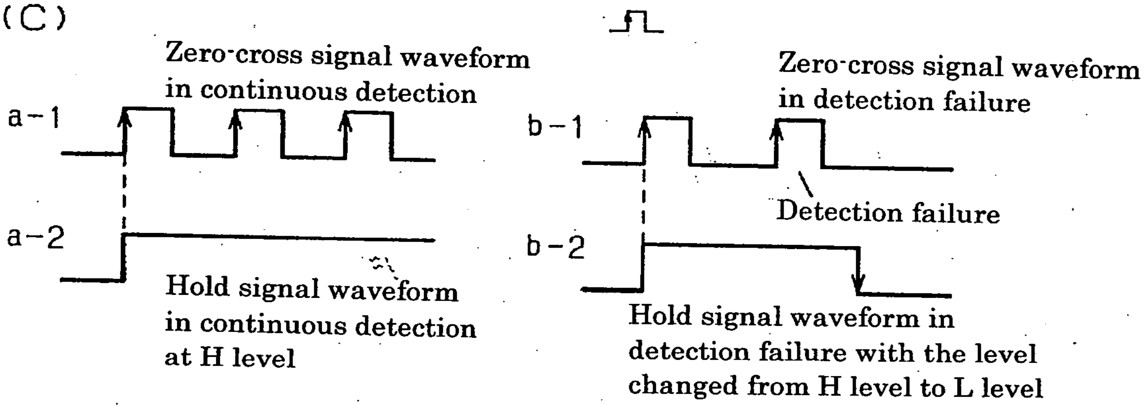
14
Zero-cross detection monitor
Vcc
12
5
Zero-cross detector
13
1
Starter
Control output
Q5
2
3
Driving pulse setter

(B)



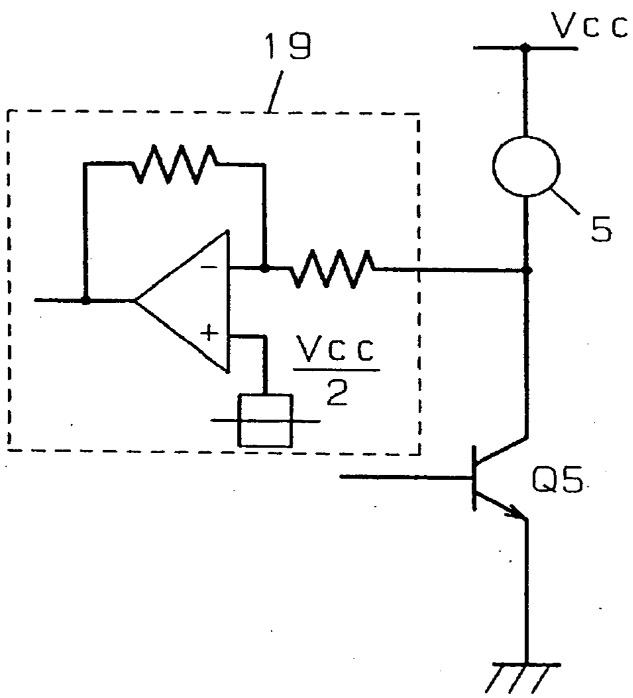
Vcc
16
5
Re-start pulse
18
17
Q5
OR
Q
A
B
Hold signal
15
Driving pulse
Zero-cross detector
13

(C)

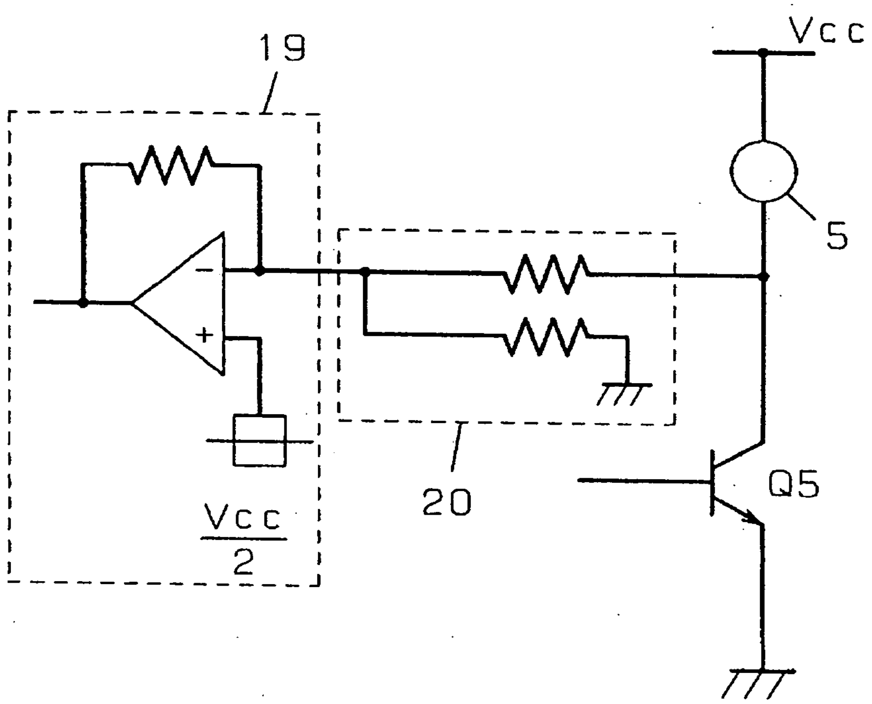


Zero-cross signal waveform in continuous detection
a-1
a-2
Hold signal waveform in continuous detection at H level
Zero-cross signal waveform in detection failure
b-1
Detection failure
b-2
Hold signal waveform in detection failure with the level changed from H level to L level

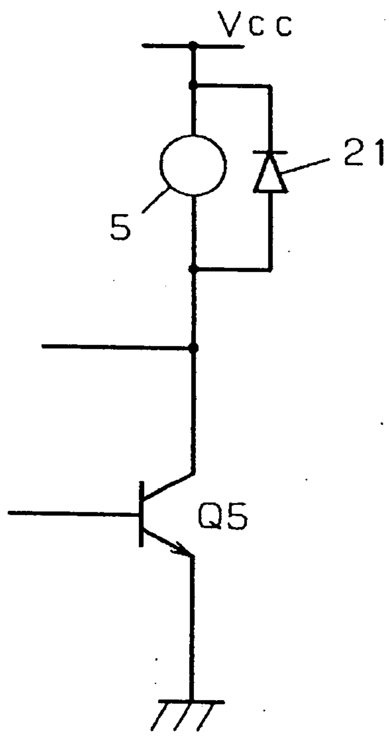
[Fig. 3]



[Fig. 4]

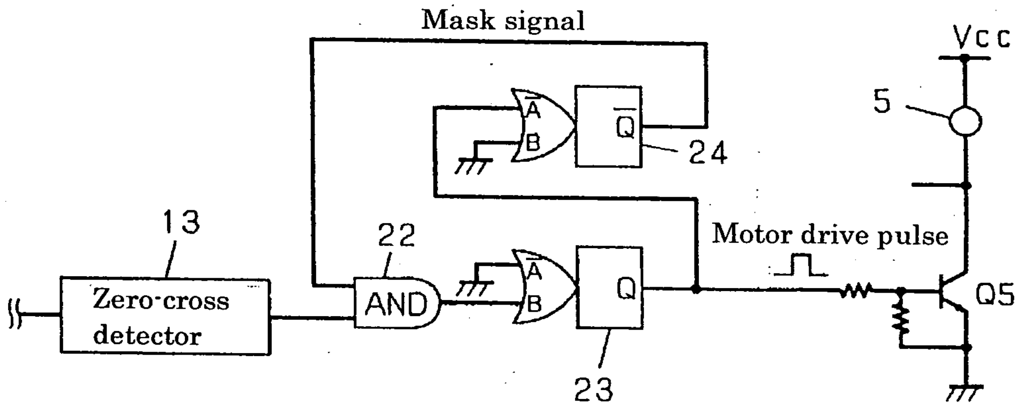


[Fig. 5]



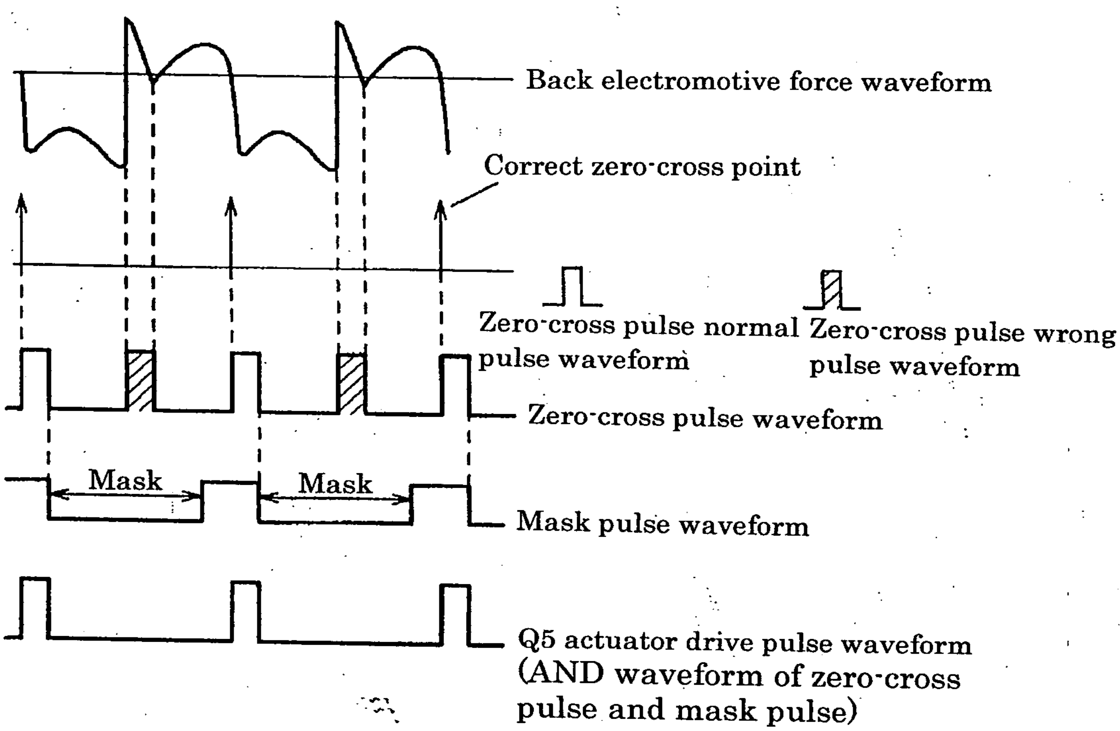
[Fig. 6]

(A)



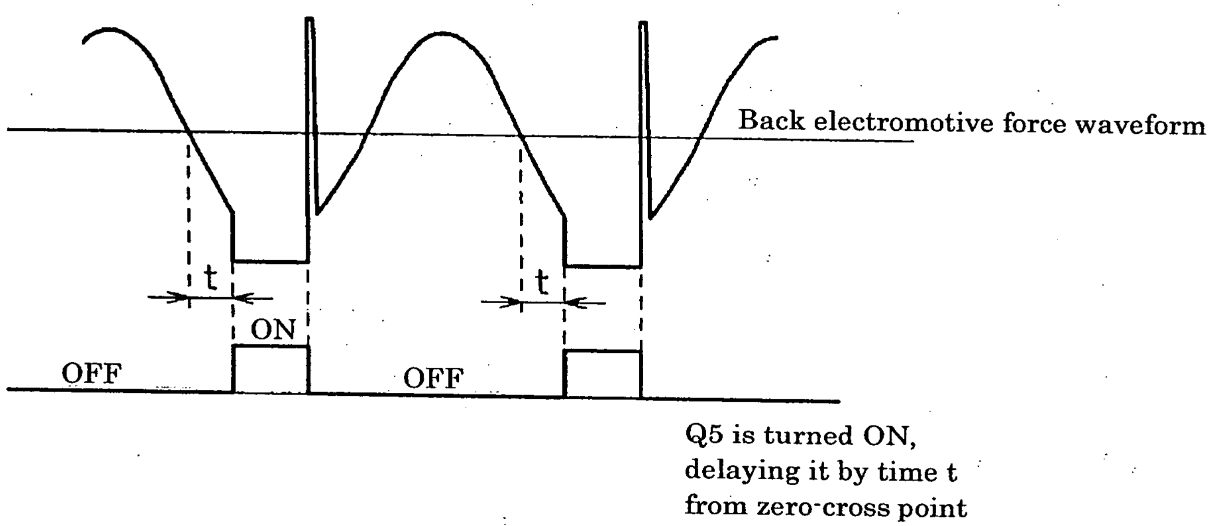
Mask signal
Vcc
5
24
13
22
Motor drive pulse
Zero-cross detector
AND
Q
Q5
23

(B)

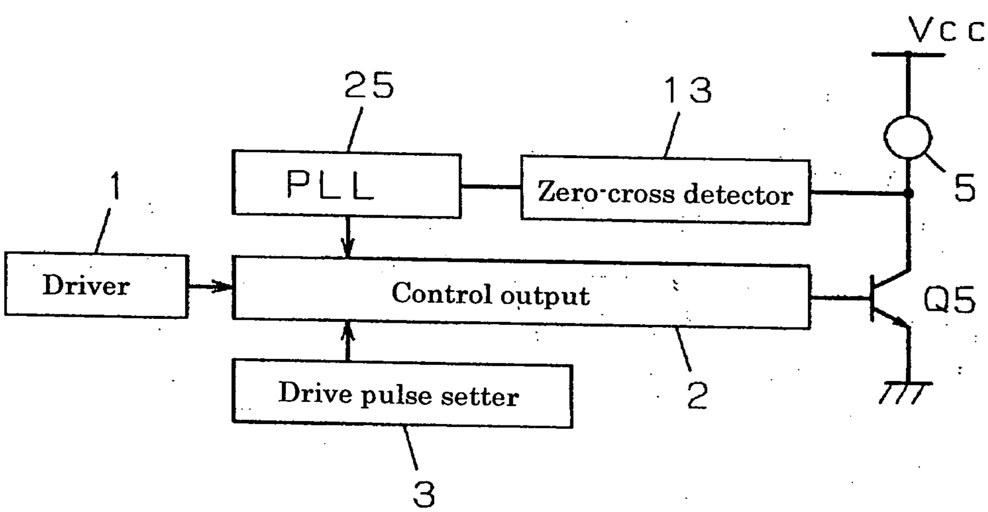


Back electromotive force waveform
Correct zero-cross point
Zero-cross pulse normal pulse waveform
Zero-cross pulse wrong pulse waveform
Zero-cross pulse waveform
Mask
Mask
Mask pulse waveform
Q5 actuator drive pulse waveform (AND waveform of zero-cross pulse and mask pulse)

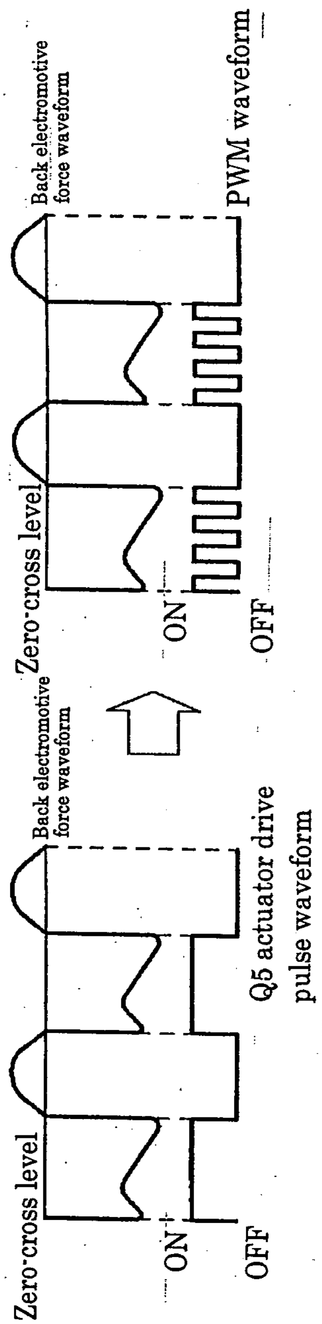
[Fig. 7]


Back electromotive force waveform
t
t
ON
OFF
OFF
Q5 is turned ON,
delaying it by time t
from zero-cross point

[Fig. 8]


Vcc
25
13
PLL
Zero-cross detector
5
1
Driver
Control output
Q5
Drive pulse setter
2
3

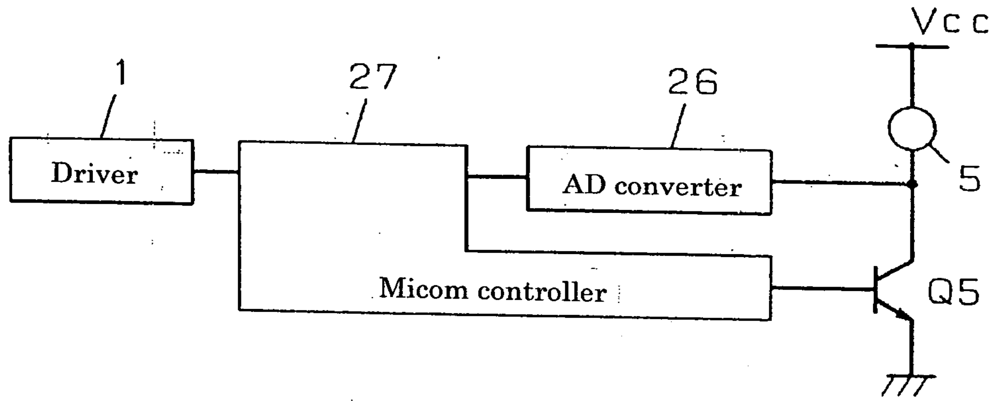
[Fig. 9]



Zero-cross level
ON
OFF
Back electromotive force waveform
Q5 actuator drive pulse waveform
Zero-cross level
ON
OFF
Back electromotive force waveform
PWM waveform

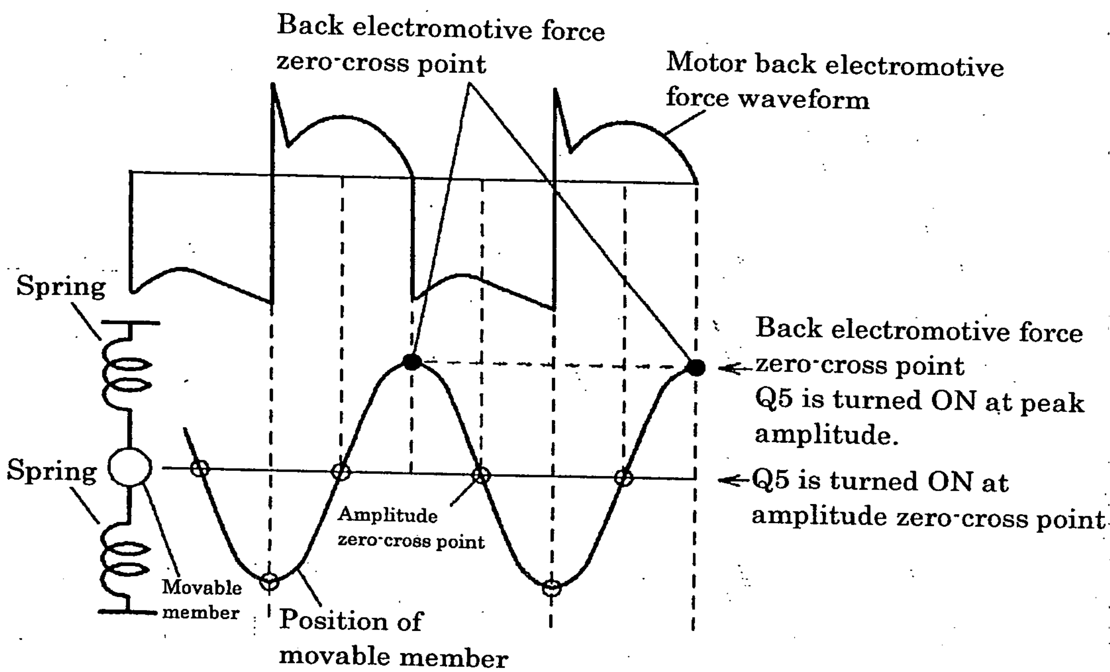
[Fig. 10]

(A)



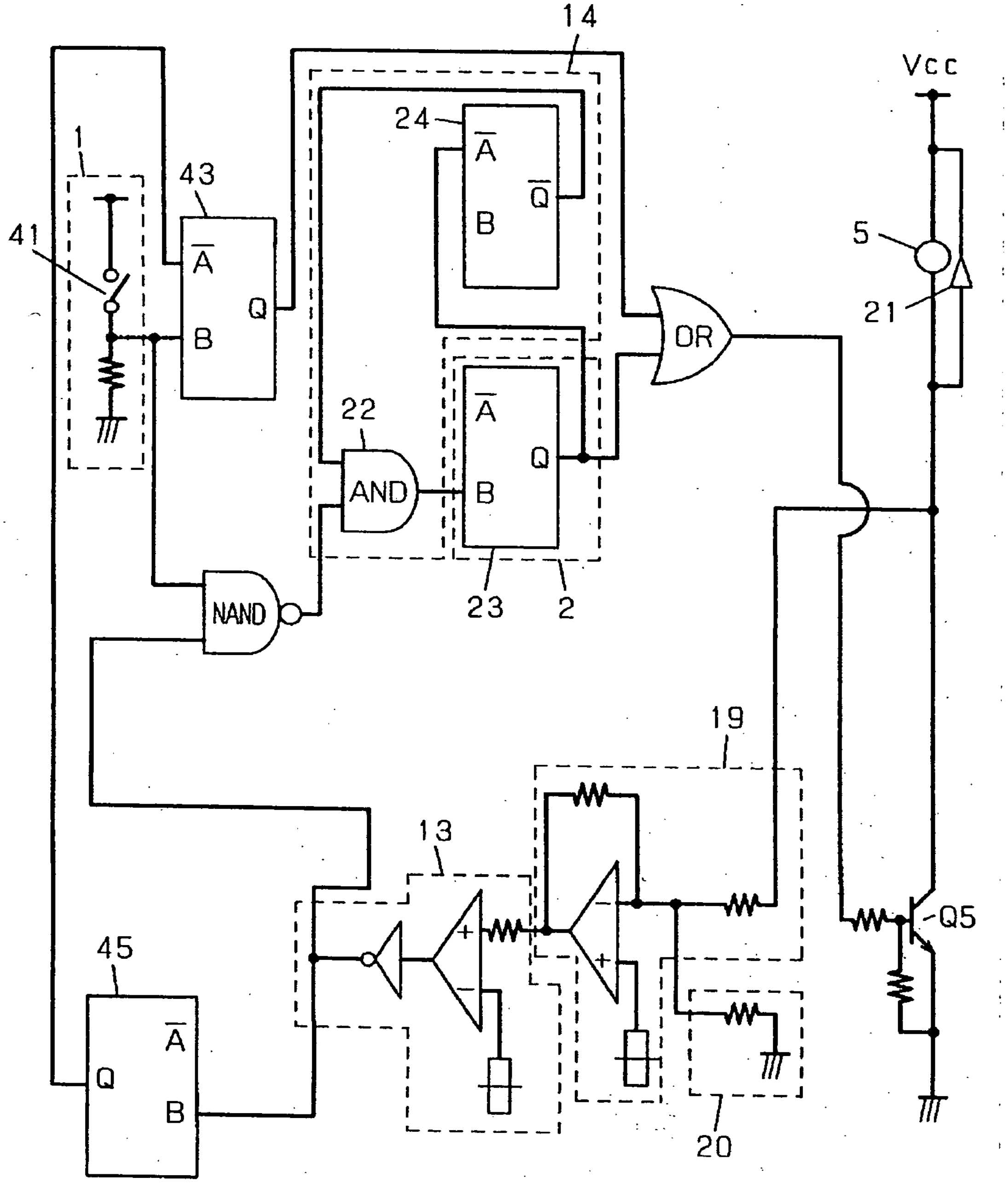
Vcc
1
27
26
Driver
AD converter
5
Micom controller
Q5

(B)



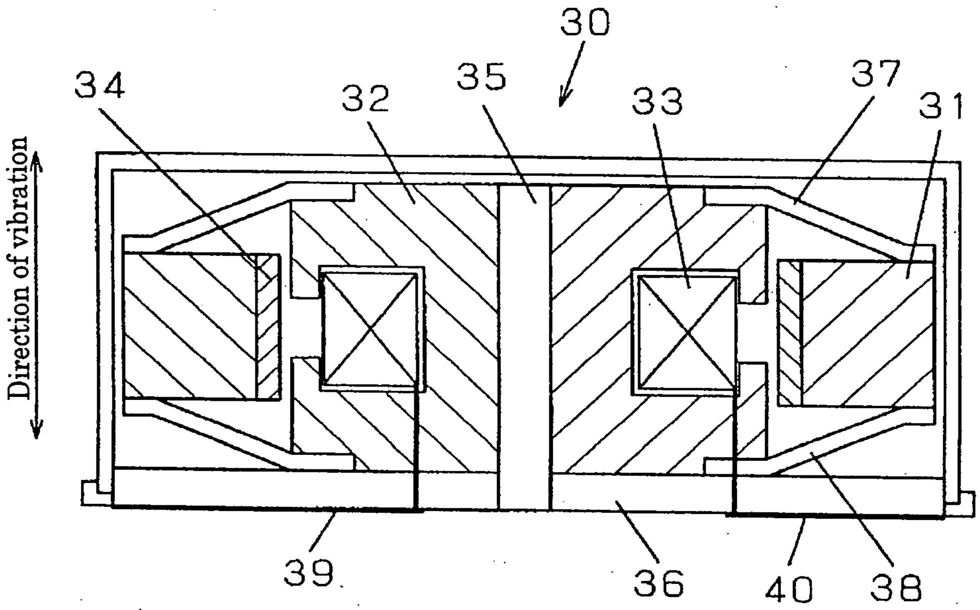
Back electromotive force zero-cross point
Motor back electromotive force waveform
Spring
Spring
Back electromotive force zero-cross point
Q5 is turned ON at peak amplitude.
Q5 is turned ON at amplitude zero-cross point
Amplitude zero-cross point
Movable member
Position of movable member

[Fig. 11]

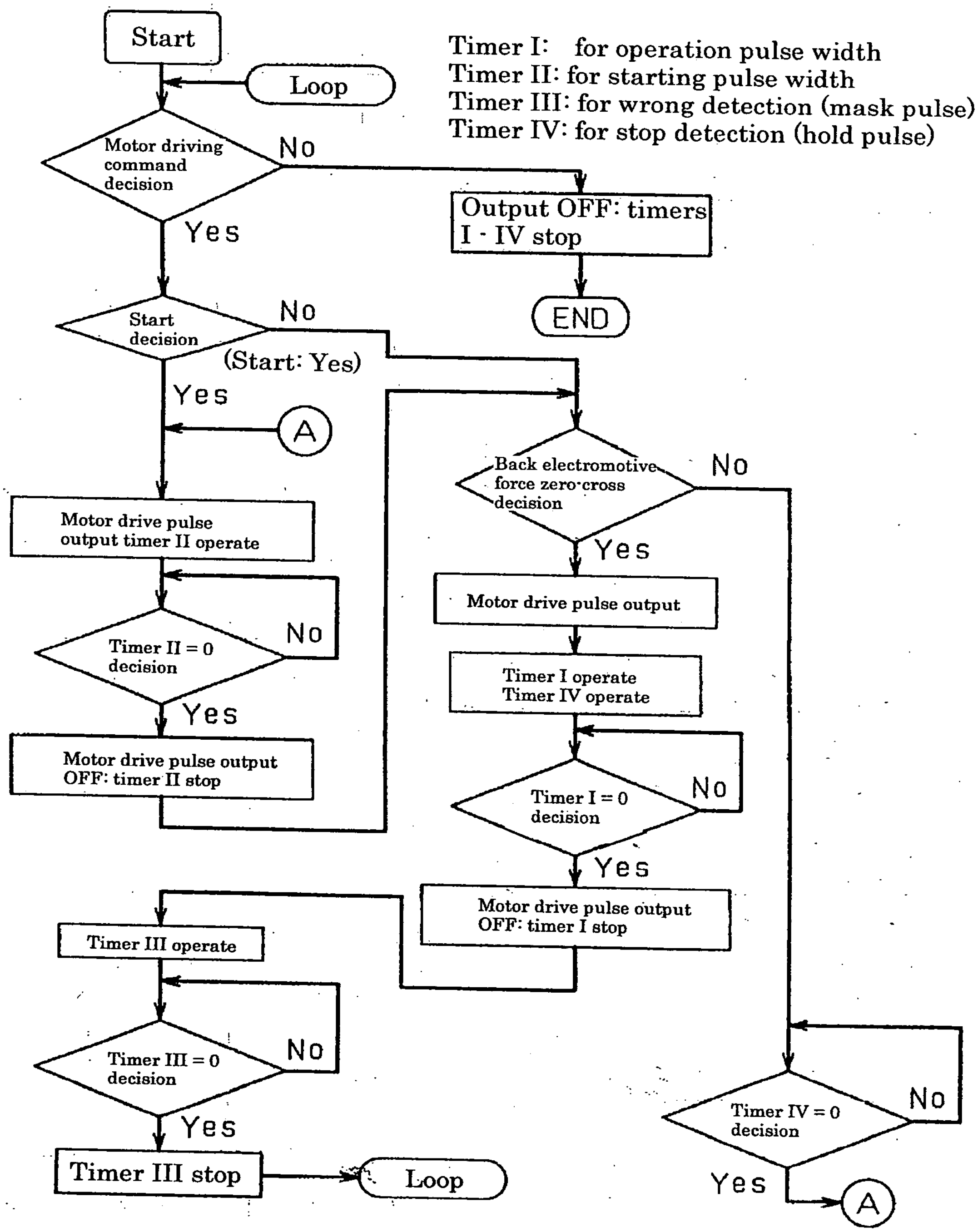


14
Vcc
24
A
Q
B
1
43
5
41
A
Q
B
OR
21
22
A
Q
AND
B
NAND
23
2
19
13
Q5
45
A
Q
B
20

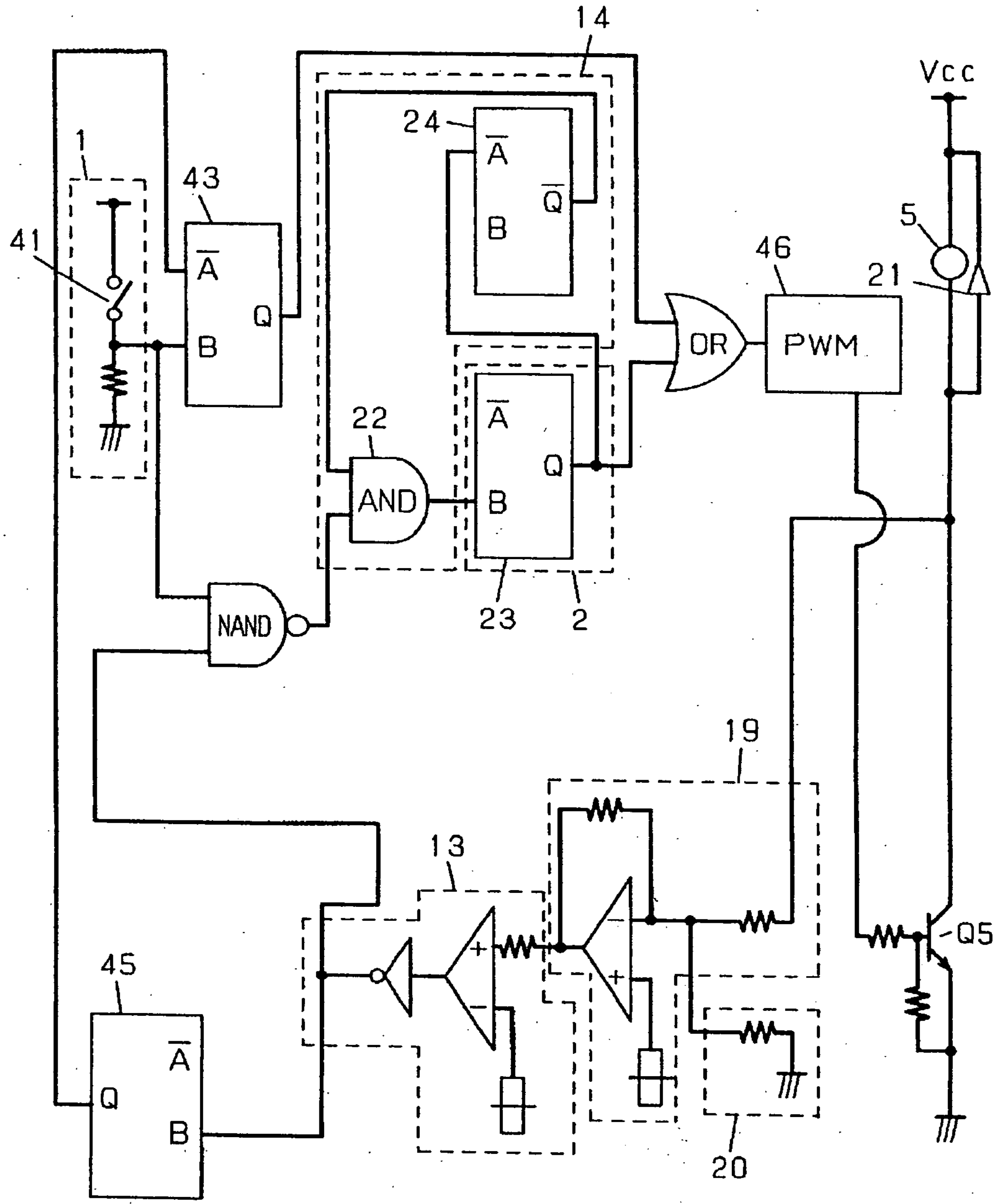
[Fig. 12]



[Fig. 13]

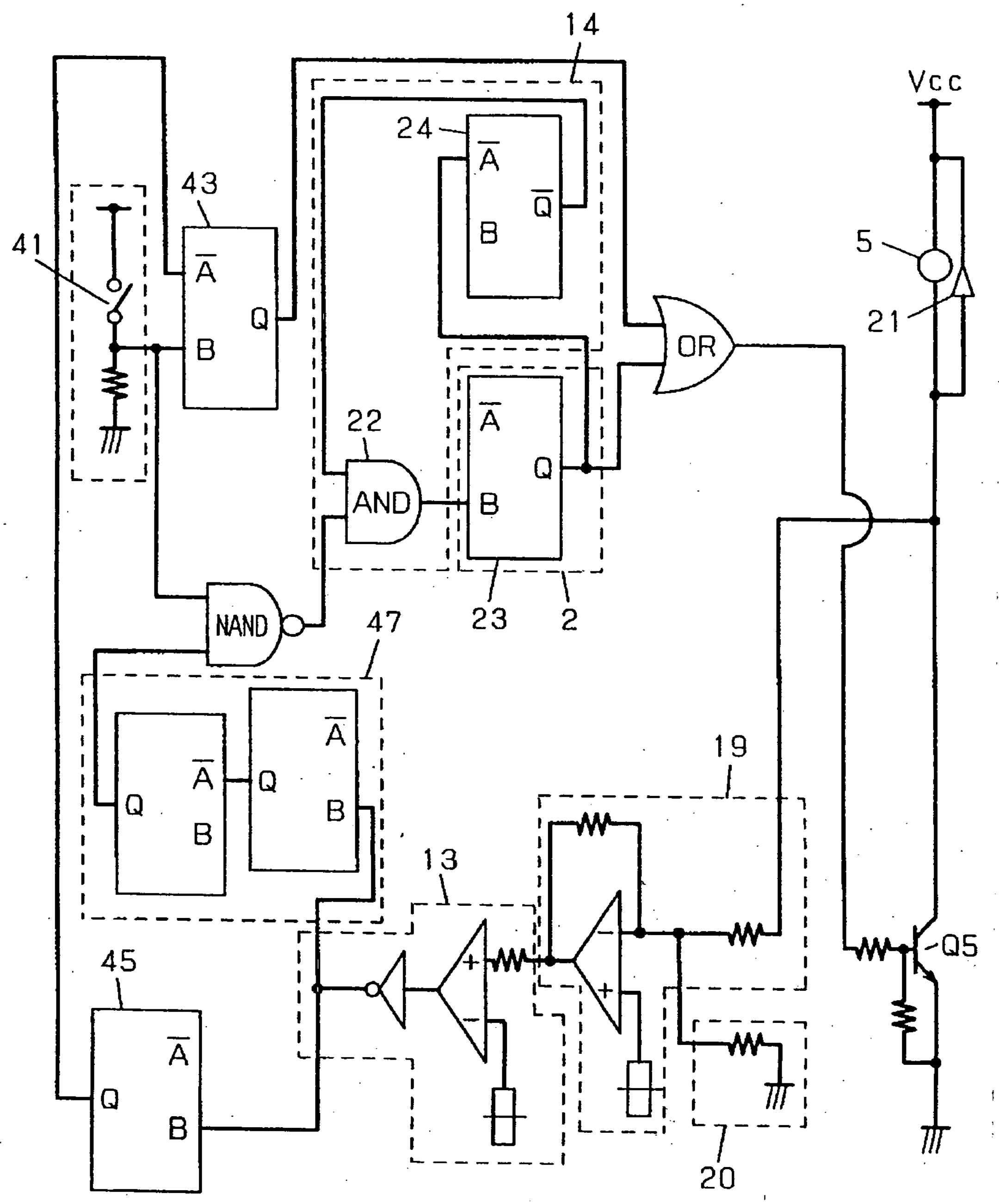

Timer I: for operation pulse width
Timer II: for starting pulse width
Timer III: for wrong detection (mask pulse)
Timer IV: for stop detection (hold pulse)
Start
Loop
Motor driving command decision
No
Yes
Output OFF: timers I - IV stop
END
Start decision
No
(Start: Yes)
Yes
A
Motor drive pulse output timer II operate
Timer II = 0 decision
No
Yes
Motor drive pulse output OFF: timer II stop
Back electromotive force zero-cross decision
No
Yes
Motor drive pulse output
Timer I operate
Timer IV operate
Timer I = 0 decision
No
Yes
Motor drive pulse output OFF: timer I stop
Timer III operate
Timer III = 0 decision
No
Yes
Timer III stop
Loop
Timer IV = 0 decision
No
Yes
A

[Fig. 14]

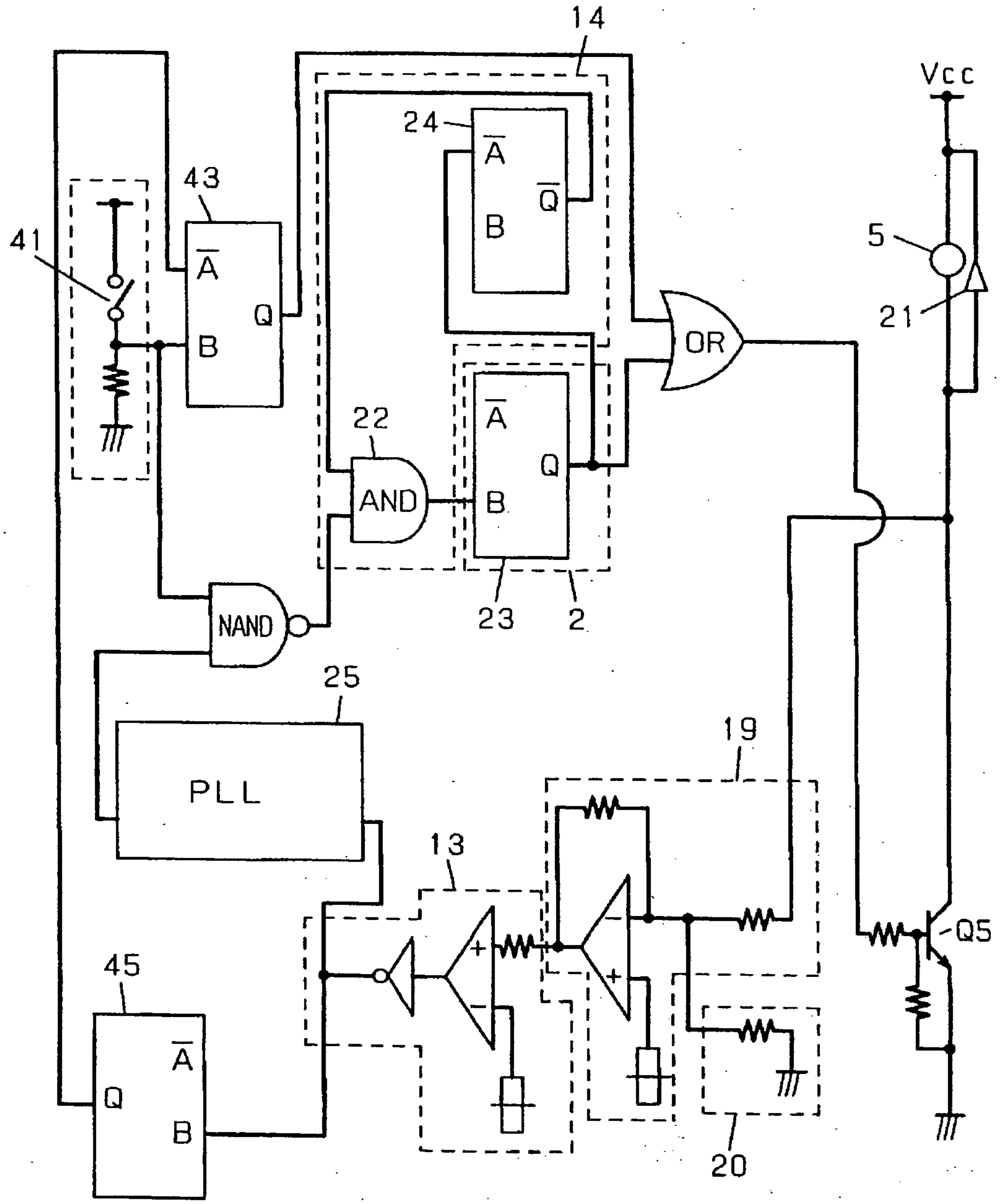


14
Vcc
24
A
Q
B
1
43
41
A
B
Q
5
46
21
OR
PWM
22
A
Q
AND
B
NAND
23
2
19
13
Q5
45
A
Q
B
20

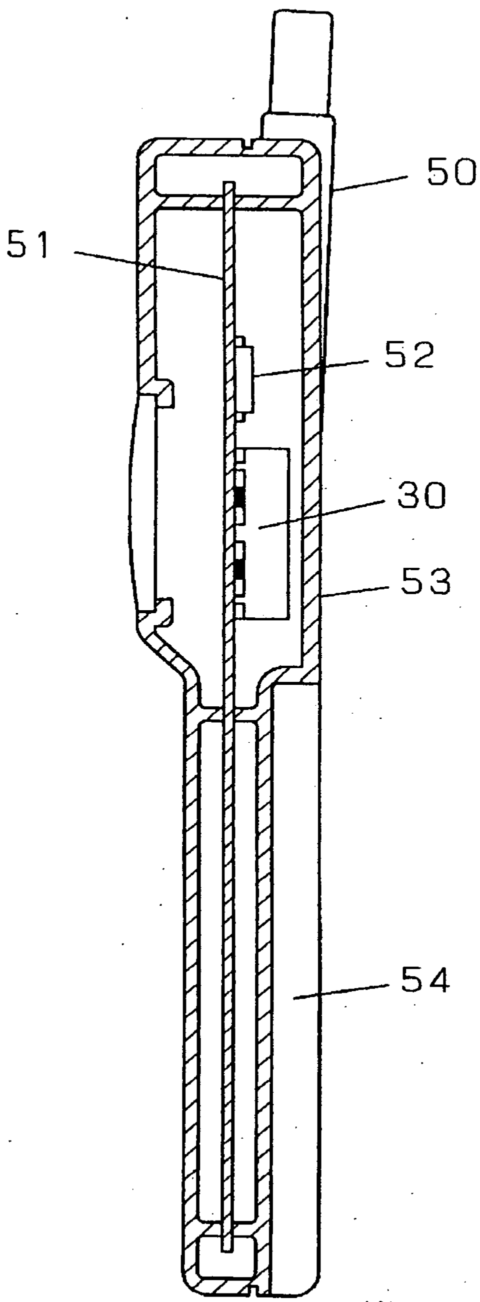
[Fig. 15]


14
Vcc
24
A
Q
B
43
41
A
B
Q
5
21
OR
22
AND
A
Q
B
23
2
NAND
47
A
Q
B
A
Q
B
19
13
Q5
45
A
Q
B
20

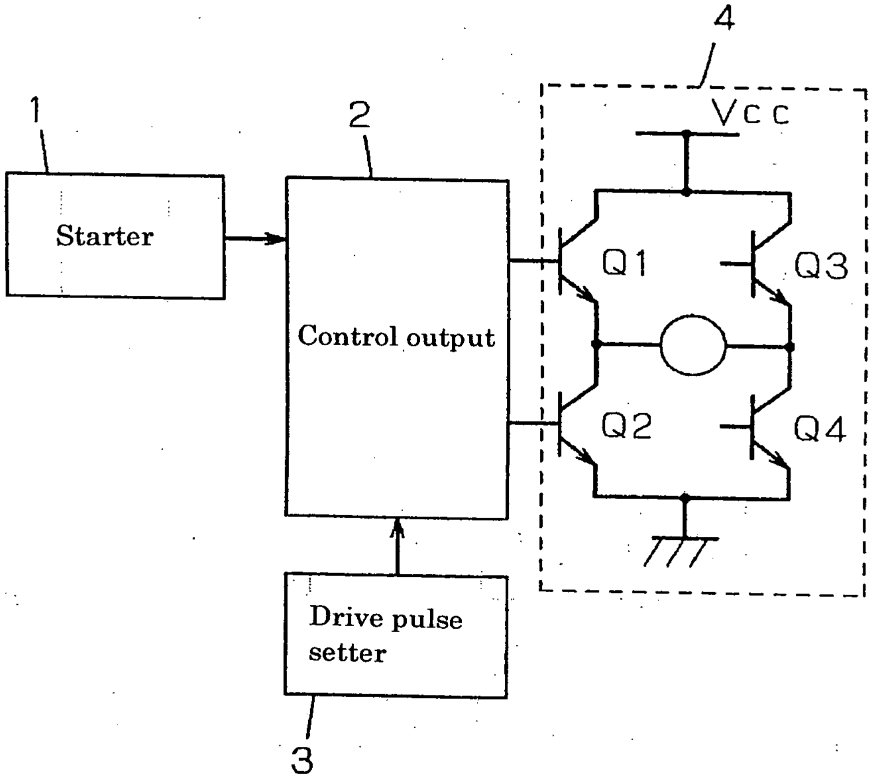
[Fig. 16]


14
Vcc
24
A
B
Q
43
5
41
A
Q
B
21
OR
22
A
Q
AND
B
NAND
23
2
25
19
PLL
13
Q5
45
A
Q
B
20

[Fig. 17]



[Fig. 18]



1
2
3
4
Starter
Control output
Drive pulse setter
Vcc
Q1
Q2
Q3
Q4

[Fig. 19]